

Management of a water distribution network by coupling GIS and hydraulic modeling: a case study of Chetouane in Algeria

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Abstract For more effective management of water distribution network in an arid region, Mapinfo GIS (8.0) software was coupled with a hydraulic model (EPANET 2.0) and applied to a case study region, Chetouane, situated in the north-west of Algeria. The area is characterized not only by water scarcity but also by poor water management practices. The results showed that a combination of GIS and modeling permits network operators to better analyze malfunctions with a resulting more rapid response as well as facilitating in an improved understanding of the work performed on the network. The grouping of GIS and modeling as an operating tool allows managers to diagnosis a network, to study solutions of problems and to predict future situations. The later can assist them in making informed decisions to ensure an acceptable performance level for optimal network operation.

Keywords Water distribution network · GIS · Database · Modeling · EPANET

Introduction

Geographic information systems (GIS) have become essential tools in the spatial and statistical analysis of water resources for more effective management (Tsihrintzis et al. 1996; Kalivas et al. 2003; Udovik 2006). Vairavamoorthy et al. (2007) even reported that such systems have been employed for spatial data management and manipulation of spacewalks. Spatial data, also known as geospatial data, is information about a physical object that can be represented by numerical values in a geographic coordinate system. GIS provides a consistent environment for viewing of the display model and the input/output data results. This ability is very useful in the decision making process. In the field of urban hydraulics, for instance, Blindu (2004), Abdelbaki and Touaibia (2011, 2014), and Abdelbaki et al. (2012) demonstrated that the use of GIS allows for a more thorough awareness of a water distribution network; thus making it easier to update a system after a change. Furthermore, for a better management of a water distribution network (WDN) it is also possible to combine in a GIS database information, such as water quantity and quality in a specific territory. It is thus important to collect in the same computer support all the information related to a water system based on geographical location. This precise knowledge of the network will improve efficiency at both the technical and administrative management levels and will enhance the quality of service provided to subscribers (Gandin and Doutre 2007).

According to Tabesh and Delavar (2003), the development of a GIS model combined with the generation of information required for effective water services management is time consuming and expensive. It has become clear that all desired management goals cannot be reached in the application of GIS in water distribution systems without a

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link to hydraulic simulation models. Additionally, coupling GIS to external models enhances the overall management efficiency of water delivery systems (Bartolin et al. 2001, 2008; Argent 2004; Vairavamorthy et al. 2007; Panagopoulos et al. 2012; Abdelbaki 2014).

Hydraulic model EPANET software (Rossman 2000) has been recognized as the standard for identifying key parameters. EPANET which first appeared in 1993 is a public domain, water distribution system modeling software package developed by the United States Environmental Protection Agency's (EPA) Water Supply and Water Resources Division. The model performs extended period simulation of hydraulic and water-quality behavior within pressurized pipe networks and was designed to be a research instrument that advances our understanding of the movement and destiny of drinking water constituents within distribution schemes (Rossman 1999, 2000). Data to be analyzed has to be entered through a graphic interface by means of property dialogs (Bartolín et al. 2008). EPANET is employed in various fields of research, where there is a need for continuous improvement (Ardešhir et al. 2006; Martinez et al. 2007; Worm et al. 2010; Guidolin et al. 2010; Yu et al. 2010; Ramesh et al. 2012; Padilla et al. 2013; Abdelbaki 2014). For example, in Algeria a methodology for implementation of GIS coupled with EPANET for the Chetouane water distribution network (WDN) has been developed to take advantage of a powerful modeling environment.

The aim of this study was to develop a more effective management system for a water distribution network in an arid area by coupling Mapinfo GIS (8.0) software with a hydraulic model (EPANET 2.0) and then applying it to a case study region, Chetouane, situated in the north-west of Algeria. Specifically, network modeling was used to analyze and to comprehend the functioning of the distribution network better in terms of diagnosing problem areas, such as supply discontinuity, leakages and replacement of worn out pipes.

Description of case study area and water distribution network

The municipality of Chetouane which is located in the North-East of Tlemcen, in Algeria in North Africa, is 5 km from the city center (Fig. 1). It represents the northern part of the town of Tlemcen and is bounded on the North-East by the municipality of Amieur, on the North-West by the municipality of Henaya, on the South-West by the town of Tlemcen, and on the South-East by the municipality of Ain Fezza (Abdelbaki et al. 2012). About 47,600 people live in 105 km² of Chetouane (DPAT 2008).

The water distribution network of Chetouane is interconnected with branched extensions and serves 4642

subscribers (ADE 2012). The network length (main pipes) is 25 km with the pipe diameter varying between 33 and 500 mm (steel and galvanized steel). The water is distributed by gravity using four tanks whose capacities are, respectively, 3000, 1000, 300 and 250 m³. The primary network performance is 51 % and the linear loss index is in the range of 15 m³/day/km (ADE 2012).

Methodology

Network modeling was employed to analyze and to simulate the Chetouane network using GIS (MapInfo 8.0) (Fig. 2). Specifically, problems were diagnosed, such as supply discontinuity, leakages and worn out pipes (Abdelbaki and Touaibia 2011, 2014). EPANET (Rossman 2000) was chosen for the simulation of the distribution of velocities and pressures. In EPANET, supply networks are defined by elements, such as nodes, pipes, valves and tanks (Guidolin et al. 2010; Worm et al. 2010).

Utilization of GIS for diagnosing the Chetouane water distribution network

The different available options in GIS allows for the acquisition of network maps and their associated characteristics (Ho et al. 2010). Each layer or level can be associated with a specific theme along with the associated alphanumeric information. These GIS systems are, therefore, particularly well adapted to the representation of drinking water supply systems (Blindu 2004).

The establishment of GIS for the Chetouane water distribution network (Figs. 2, 3) was motivated by the fact that it allows spatial analysis by combining layers of information stored in the database (Ayrat and Sauvagnargues-Lesage 2009; Gomarasca, 2010; Tena-Chollet et al. 2010). Figure 4 illustrates an example of applications where the galvanized steel pipes having a diameter less than 80 mm are selected. Furthermore, the constitution of the Chetouane water distribution network data base allows the user to make queries and to get answers.

Query results obtained were a form of diagnosis (Blindu 2004). By identifying places where malfunction events could occur, the operator may identify areas of the network with serious issues, and thereafter take decisions to improve the network status.

GIS-EPANET transfer and modeling of the Chetouane water distribution network

GIS-EPANET conversion was performed using DXF2EPA (Ostfeld and Salomons 2005; Salomons 2005). The latter is free software which can convert all elements from GIS,

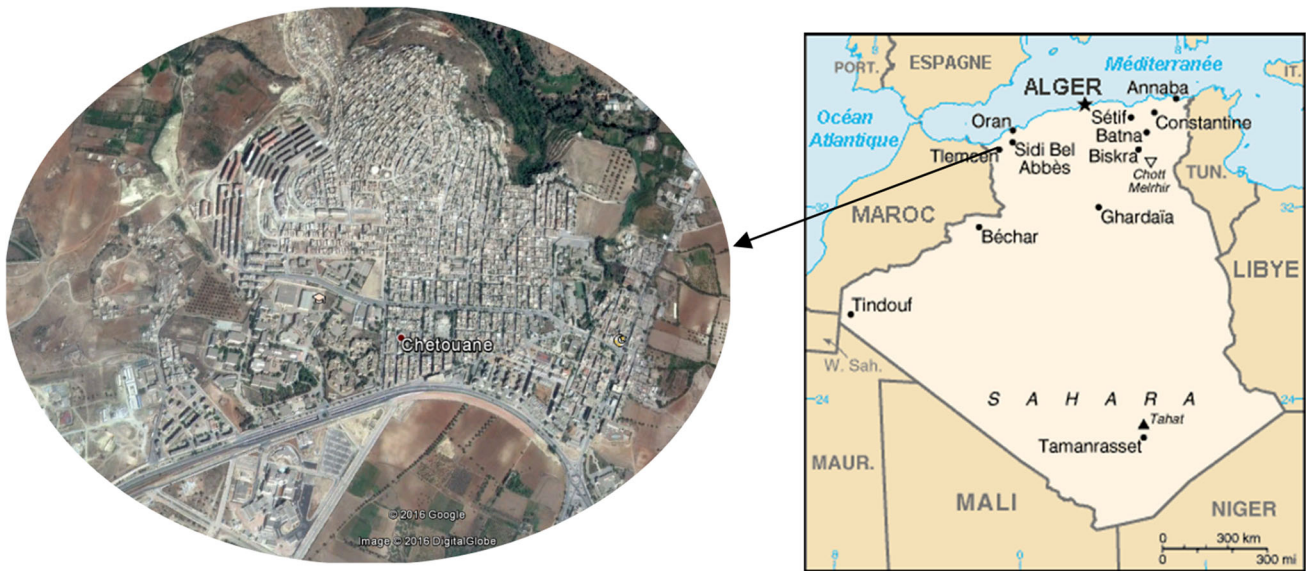


Fig. 1 Location of the case study area

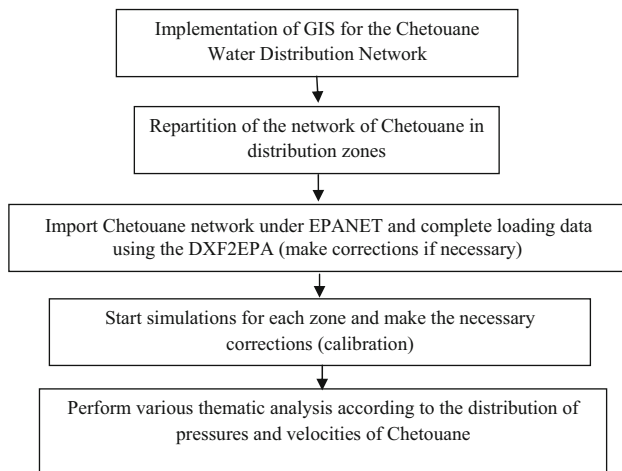


Fig. 2 Methodology flowchart

such as lines and polylines in layers at DXF format, in a set of pipes and fittings in EPANET (Rossman 2000). Additional elements such as tanks, pumps and valves should be added manually to the model in EPANET (Worm et al. 2010). The conversion software can calculate the lengths of pipes; while other network data, such as elevations nodes, water need and pipe diameters must be modified using EPANET (Rossman 2000) after the converted file is loaded. After the conversion of the different layers network data, such as diameters, pipe roughness, altitudes, reservoirs and valve characteristics is input into the system. The network consumption is defined in the nodes of the water distribution network, which allocates the flow based on the needs of the population; this rate is divided according to the importance of consumption points in the network. The

modeling goal is to establish a consumption profile for each part of the network starting from the 296 nodes needs of the Chetouane network and its peak flow. Figure 5 shows some of the scenarios of the water distribution network operation.

Results and discussion

According to EPANET network analysis of the pressure distribution, it was found that 115 of the 296 demand nodes (i.e., 39 %) have a pressure greater than 6 bar (Fig. 6). This signifies that more than 39 % of the network nodes may have serious leakage problems. Unacceptable noise inside the customer houses was also reported (Dupont 1979; Bonnin 1986; Valiron 1994). Three of the 296 nodes had a pressure lower than 1 bar, suggesting that 1 % of the nodes present may have broken pipes. It can be argued that subscribers of these regions are not properly served (Dupont 1979; Bonnin 1986; Gomella 1985; Tatiétsé and Rodriguez 2001). Furthermore, 178 of the 296 nodes (i.e., 60 %) had a pressure between 1 and 6 bar. This means that 60 % of the nodes were in the standard range and were working properly as proposed by Dupont (1979) and Bonnin (1986).

Analysis of the velocity distribution indicated that 200 out of 306 pipes (i.e., 65 %) were characterized by water velocity less than 0.5 m/s (Fig. 7). This can result in damage to 65 % of the network pipes since low velocity can cause deposit build up as a consequence of settling and low shear (Gomella 1985). In addition, 64 pipes among 306 (i.e., 21 %) had a velocity between 0.5 and 1.5 m/s, which

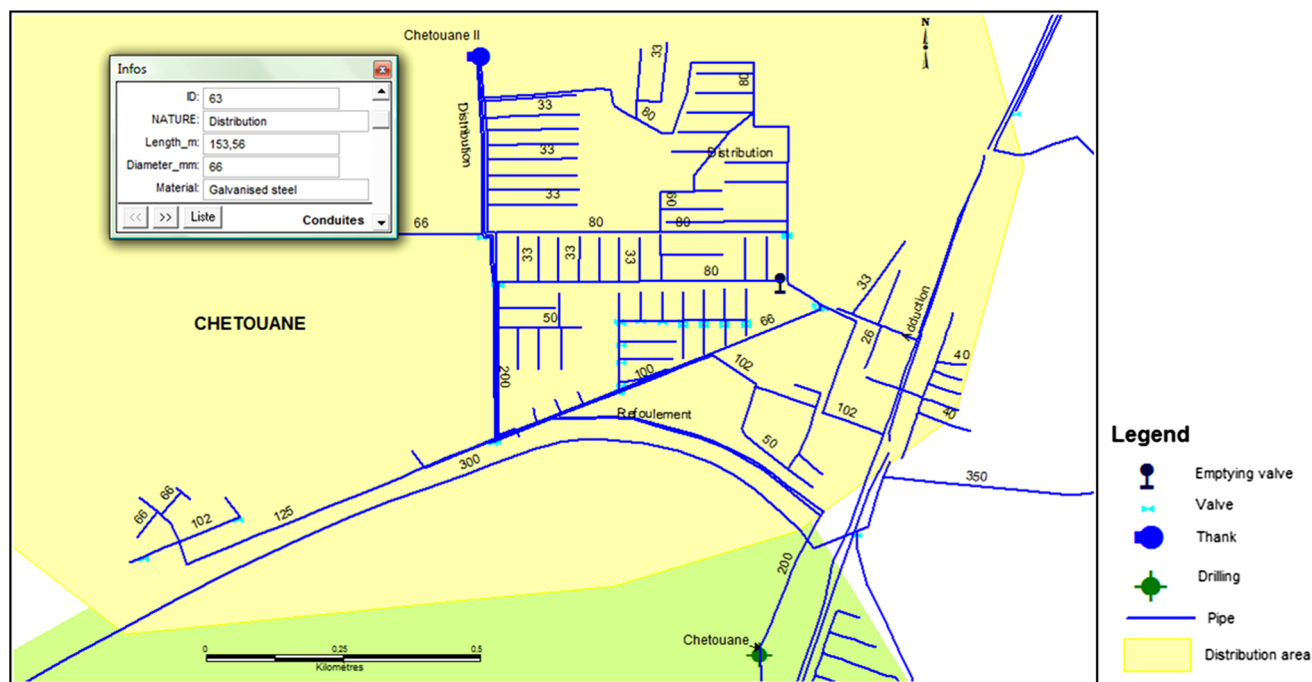


Fig. 3 Extract of water distribution network of Chetouane

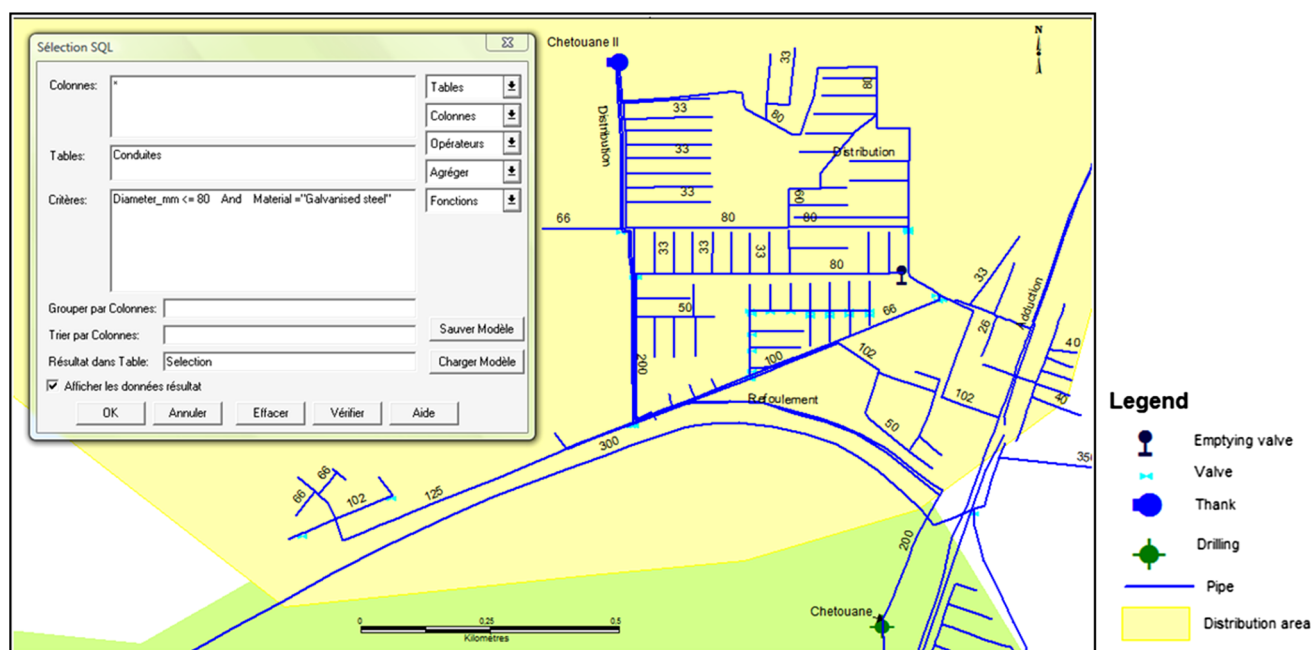


Fig. 4 Example of GIS applications

is in the acceptable range according to international standards (Dupont 1979; Bonnin 1986). However, the remaining 42 pipes (i.e., 14 %) had a velocity greater than 1.5 m/s, which is not ideal. Thus, 14 % of the network may be damaged by an internal erosion or abrasion, due to shear effects caused by high fluid flow rates (Dupont 1979; Bonnin 1986).

The overall analysis indicated that the Chetouane water distribution network is not functioning ideally. Several actions are required to improve the performance and to reduce the rate of leakage in the network. Updating of the network should take into consideration the operating conditions (i.e., velocity, pressure, soil characteristics). It is important to note that the storage and updating of

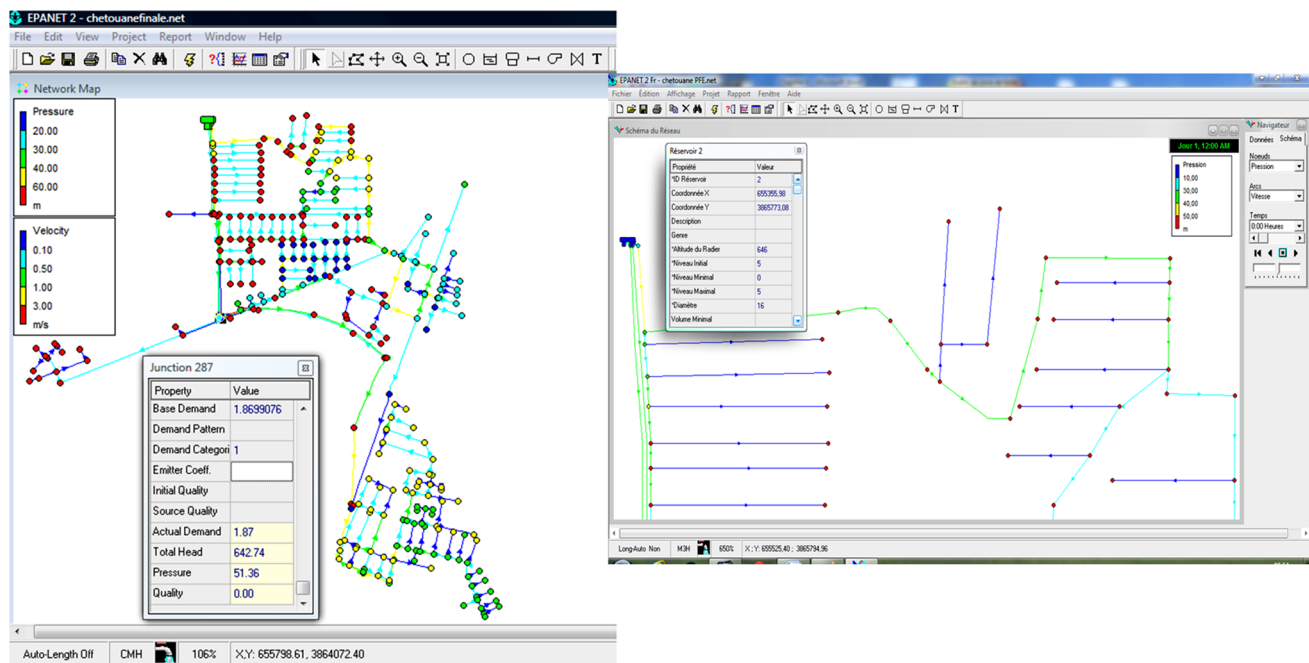


Fig. 5 Scenarios for water distribution network modeled by EPANET

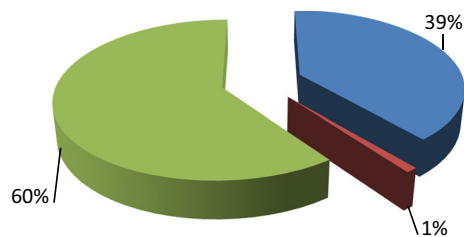


Fig. 6 Pressure distribution in the nodes of the WDN of Chetouane

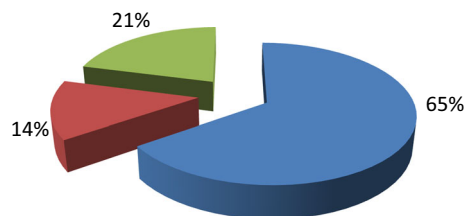


Fig. 7 Velocity distribution in the WDN of Chetouane

descriptive and spatial operations data allows the operators and managers to access the history of operating problems of specific parts of the network. Knowing where breaks have occurred, and where renewals have been made, for instance, is very useful for predicting future interventions in the network, and thus for budgeting purposes.

The results showed that the combination of GIS and modeling allows network operators to have a management tool that can analyze malfunctions with a response to any

incident that may occur and facilitate understanding of the work performed on the network. Furthermore, the grouping of GIS and modeling as an operating tool allows managers to diagnosis the network, to study the solutions of problems and to predict future situations. The later can assist them in making more informed decisions to ensure an acceptable performance level for optimal network operation.

Conclusion

This study has shown a methodology for improved management of a water distribution network by coupling Mapinfo GIS 8.0 software with hydraulic modeling (EPANET2.0). By applying this methodology to a case study region of Chetouane in Algeria, it revealed which areas of the network are working properly and which areas need to be changed. In addition, the storage and updating of descriptive and spatial operations data allows operators and managers to access the history of operating problems of specific parts of the network. Knowing where fractures have occurred, and where renewals have been made, for instance, is very useful for predicting future interventions in the network, and thus for budgeting purposes.

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